L A B COASTAL

ANNUAL REPORT

2001

ISSN 1465- 8542

Published April 2002

CONTENTS

ANNUAL REPORT 2001
L A B COASTAL

About LAB Coastal

MISSION STATEMENT

To harness ecological research to integrated land management especially in the coastal zone.

VISION STATEMENT

L A B Coastal initiates, conducts and publishes high quality research into ecological processes, particularly in the coastal zone, and undertakes commissioned research and consultancy into specific land management problems with special reference to the coastal zone. This facilitates the integrated management of the natural resources of the living coastline.

OBJECTIVES

LAB Coastal offers a client-orientated and flexible approach to survey, research, monitoring and management. The company aims to provide the highest quality services for the assessment of the effects of environmental change on ecosystems, environmental impact assessments, system design for environmental monitoring and simulation modelling for habitat management, restoration and creation.

LAB Coastal is, however, at the same time deeply committed to basic research. It is often assumed that this can be side-stepped in order to get down to commissioned research. This is to neglect the fundamental scientific truths which must underpin any work in the applied field. Understanding of the underlying principles is essential for the effective long-term management of all natural and created ecosystems.

CLIENTS

Clients have included the EU (CEE DG XII), within the EUROSAM and ISLED programmes, the MOD and civil engineering firms.

ACTIVITIES IN 2001

In the fourth full year of its existence LAB Coastal has undergone further technical consolidation coupled with continuing progress in the current and future research activities. The laboratory, library and computing facilities have been further developed to ensure maximum efficiency as regards both client-oriented and basic research. The highlight of 2001 has undoubtedly been the final field season of the ISLED programme and, with the submission in March of the final report, the completion of the project. The completion of the ISLED and EUROSAM Projects (see under Research Projects, p. 6) does not mean that work on the topics covered is at an end. Work done under these two major projects has produced a large volume of data and work is continuing on the analysis of this data and, in close collaboration with colleagues in other organisations, on the publication of these data through the production of scientific papers. This has already resulted in the continued flow of scientific papers and contract reports (see 'Publications', p. 31).

Key aspects of the research programmes set up during the course of the ISLED and EUROSAM projects are being maintained particularly the long-term monitoring of salt marsh changes and the extension of the EUROSAM salt marsh flux studies to selected Scottish sea lochs where exchanges of organic matter and mineral nutrients occur under clearly defined circumstances (see under Research Projects, p. 11).

The Contract with the Ministry of Defence to assess the experimental grazing studies at Braunton Burrows, north Devon, was renewed for a further three years, partly as a result of the delay to the work in 2001 following the Foot and Mouth epidemic (see under Research Projects, p. 14).
Efforts by L A B Coastal to secure medium to long-term funding for future projects is continuing in order to build on current achievements and to improve further the scientific background for effective and environmentally-friendly future coastal zone management techniques.

Programme Performance

RESEARCH STRATEGY

The philosophy of LAB Coastal is that the foundation of all its work is basic research. While the primary objective must remain the application of this high grade research to practical problems of ecological and conservation management this can only be done if the basic scientific information is available. LAB in the UK and abroad. Added Coastal is currently engaged in research into coastal problems both urgency is given to such work by the threat of rising sea level and the consequent encroachment of the sea on to areas which are valuable for wild life as well as on to economically sensitive areas, such as industrial and residential zones.

RESEARCH PROJECTS

EUROSAM

The EUROSAM project was officially ended in 2000 and the completion of the project was marked by the appearance, as a CD, of the Decision Support System in April 2001 (S.L.Brown and R.Cox (eds), EUROSAM Decision Support System, Version 1.1.i. EU Environment and Climate RTD Programme - European Salt Marshes Modelling - Contract Number ENV4-CT97-0436). This effectively completed the research programme but, for members of the research team, work on the considerable amount of data is continuing with the aim of producing further scientific papers and key aspects of the work are being continued and developed . For L A B Coastal this includes the process studies in the Scottish lochs (see under Research Projects, p. 11) and the modelling of organic and nitrogen fluxes.

ISLED

The ISLED project was completed early in 2000 with a final programme of field work which was concluded in January. The analysis of the data collected during this project continued through the year and resulted in the publication of a paper describing the experimental work done in the mesocosm on the effect of salt marsh plant species of interactions between sediment deposition and tidal innundation (see:- Boorman, L.A., Hazelden, J. & Boorman, M. 2000 in Publications. p. 11).

Among various investigations on short term sedimentation rates at sites in the Westerschelde measurements were made of the rate of sedimentation at various heights above the surface of the marsh (Fig. 1.). The results obtained showed the importance of the vegetation in decreasing water velocities as the surface of the sediment was approached. Within 100 mm of the surface the rate of sediment deposition dropped fourfold (Fig. 2.) but remained relatively constant up to 300 mm, the maximum height investigated. It was noted that while the tallest plants in the vegetation at the experimental site reached a height of some 500 mm or more the

bulk of the vegetation which could reduce the water velocity was within 100 mm of the surface.

Figure 1. *Determination of the rate of sedimentation during a single tide at Waarde marsh, in the Westerschelde. The weight of sediment deposited on the papers on the mud surface were close to that measured when the paper holders when used at that level.*

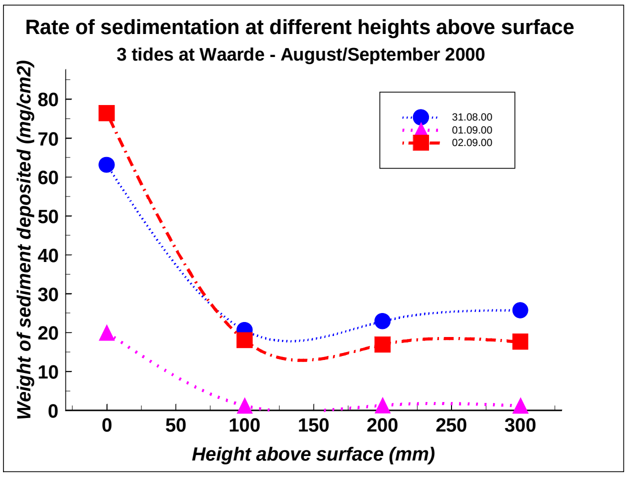


Figure 2. *Determination of weight of sediment deposited during a single tide at different heights above the surface of the sediment.*

It was clear from these and other experiments that there was a considerable gap between the short term accretion rates measured over one or two tides and the cumulative accretion over periods of months or years. The high short-terms rates measured indicated that there was a substantial secondary reworking of deposited sediment. This underlined that the vegetation had a dual function. The vegetation increased long-term accretion both by slowing the velocity of the water over the marsh surface thus increasing direct sedimentation and by stabilising the marsh surface reducing secondary erosion. So far it has not proved possible to develop a method of determining rates of secondary erosion.

Overall sediment budgets for whole estuaries are clearly very important but the current studies indicate the importance of the recycling of material within individual salt marsh/mud flat systems. It was noted, for example, that high rates of sediment deposition at Ellewoutsdijk seem to be linked to the erosion of material from the cliff face at the seaward edge of the marsh. It was calculated that the material being lost from cliff erosion in the western half of the marsh corresponded closely with the material required to account for the annual rate of accretion measured over a period of three years. It was also estimated that with the great extent of mudflats fronting the marsh only small amounts of material would be need to maintain marsh accretion rates. While these studies showed clearly both the variation in sediment deposition rates and in net accretion rates differences between these two figures showed that there was also significant recycling of sediment within the salt marsh itself. Although the vegetation cover would increase the stability of deposited sediment, water flow while the marsh was covered by the tide and also rain-wash could remobilise this freshly deposited sediment within the marsh system.

While long-term sedimentation rates (over years), even in a dynamic area like the Westerschelde, are generally quite low and typically of the order of a few millimetres per year these studies have shown that within these mean rates there is considerable variation with episodes of rapid accretion or major erosion alternating with quiet periods and slow rates of change. The survival of any salt marsh depends on the ability of the vegetation cover to respond to change. Any increase in accretion rates might be expected to be beneficial for the vertical growth of the marsh. However, if there were high rates of accretion the vegetation might not be able to respond. Similarly although in theory marshes can respond to rising sea levels by landward migration this process will only be effective if the salt marsh plants are able to withstand the enhanced rates of accretion that generally follow the erosion of the lower marsh zones and, in addition, if the changes are sufficiently slow for the necessary changes in the vegetation to occur.

The data from the mesocosm studies indicated that even the more sensitive marsh species were only likely to be affected seriously by sediment deposition corresponding to rates of accretion equivalent to 30 mm yr^{-1}. Although these are rates approaching an order of magnitude greater than the typical long term accretion rates observed in the field, field data indicated that over such periods, local sedimentation rates were often as high as annual equivalents of 30-40 mm yr^{-1} or more. These are rates that are likely to have negative consequences for the vegetation, particularly those plant species with a rosette or prostrate growth form in their early stages of growth.

Figure 3. *Seedlings of Aster tripolium growing vigorously in a mesocosm under conditions of enhanced rates of sedimentation and high duration of inundation.*

The plant species characteristic of the lower salt marsh, *Aster tripolium* and *Salicornia europaea* agg*.,* were not only tolerant of high frequencies of inundation (Fig. 3.) but they were also the most tolerant of high rates of sediment addition (even benefiting from it) whereas the higher marsh species *Limonium vulgare* was intolerant of anything more than moderate rates of accretion. Interestingly, *Triglochin maritimum*, which often occurs in the Westerschelde marshes (and elsewhere) in areas where there has been some form of disturbance appeared to be particularly tolerant of high rates of accretion although rather sensitive to the higher inundation frequencies (Fig. 4.).

Figure 4. *Seedlings of* Triglochin maritimum *growing vigorously in a mesocosm under conditions of low duration of inundation but enhanced rates of sedimentation.*

There appear to be three crucial problems in assessing the likely effects of changing sedimentation rates on salt marsh vegetation. Firstly, consideration must be given to the intolerance of seedlings and small plants of key salt marsh species to high rates of sediment deposition, either in particular places or over relatively short periods of time. Plants can still be affected even when there are only moderate overall annual accretion rates for a particular area.

Secondly, at present, it is very difficult to predict the details or even the extent to which sediment can recirculate within the salt marsh system and there are implications here both with regard to the effect of the vegetation on sediment deposition and the effect of sediment deposition on the vegetation. Finally, the vegetation may have the theoretical ability to respond to defined changes in sediment and inundation regimes but this will only hold true if the speed of these changes does not exceed the ability of the plants themselves to respond by migration and re-establishment. Even when the rate of change is well within the natural tolerance limits of the vegetation problems can still be caused by even quite limited periods of unfavourable conditions.

SCOTTISH LOCH STUDIES

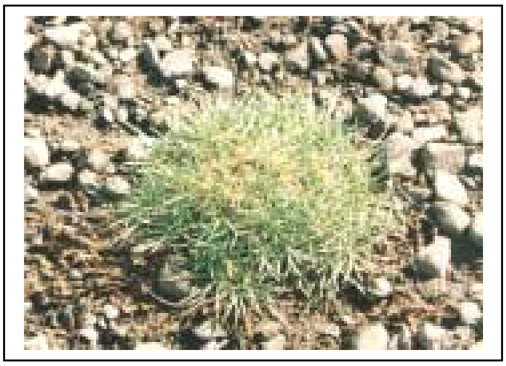
Much of the coast of the Scottish Highlands is steep and rocky with very limited exchanges between land and sea but the abundant sea lochs provide a dynamic link between the two. Experimental work over the past ten years and especially the recent work under the EUROSAM Project (see under Research Projects, p. 6). has shown that salt marshes can play a key role in linking a range of terrestrial and marine communities with up to 40% of their primary productivity being exported. Recently L A B Coastal extended the work already being done on four selected sites in Lochaber, on the west coast of Scotland, to include a study site on the island of Skye some 30 km to the north west. Comparative studies are in progress to compare the ecosystem dynamics in lochs with varying proportions of salt marsh and contrasting hydrodynamics. The sea lochs of the Western Highlands vary greatly in the relative size of the freshwater catchment, the proportion of intertidal and the mean depth at low water as well as the proportion of salt marsh. In contrast to southern salt marshes the sediment supply is often very limited and generally has a higher proportion of coarser particles. The high rainfall and humidity of the area facilitates the accumulation of organic matter in salt marsh soils. Together these factors have created areas of a unique habitat with a limited distribution along the coast of the Western Highlands, areas which nevertheless play an important role in linking terrestrial and marine communities. Increasing rates of sea level rise, as a result of global warming, are likely to overtake rates of isostatic adjustment and augment existing anthropogenic threats to these special areas.

All the five marshes studied show extensive high marsh and transition communities but rather restricted lower marsh and pioneer communities compared with those of salt marshes elsewhere. Nevertheless the productivity of these salt marsh plant communities and their vertical range in the marsh zonation are comparable. In more exposed areas, however, salt spray can result in the occurrence of salt marsh vegetation well above the levels, in relation to the tides, normally expected.

Loch Beag is a relatively small sea loch on the west coast of Skye set in a steep-sided valley (Fig. 5.). There are approximately 4.7 hectares of salt marsh at the head of the loch (Figs. 6 - 8). Comparisons are being made on the comparative species composition, development and functioning of the salt marsh areas of Loch Beag and of the four larger Lochaber lochs. Loch Beag was chosen for the initial flux measurements because of the existence of a road bridge across the lower part of the loch which provides both access and a well defined sampling point (Fig. 9).

Figure 5. *View of Loch Beag, Skye, looking south from Dùn Garsin Brock. The sea is to the top right of the picture and the area of salt marsh to the bottom left.*

Figure 6. *Main area of upper salt marsh at Loch Beag, Skye. In the lowest parts the vegetation is dominated by* Armeria maritima *and* Puccinellia maritima, *while higher areas are dominated by a mixture of* Festuca rubra *and* Armeria maritima*. Between the high marsh and the freshwater marsh there is a transition zone dominated by various species of* Juncus *and some patches of* Iris pseudacorus*.*



Figures 7 & 8 *Pioneer salt marsh at the south western edge of the marsh at Loch Beag, Skye. The scatted clumps of pioneer species such as* Armeria maritima *and* Puccinellia maritima *coalesce into more or less continuous vegetation cover.*

Preliminary results from flux studies at Loch Beag (Fig. 9) indicate that the system is particularly dynamic with very variable rates of exchange of organic matter and sediment. It would appear that sediment accretion rates are generally low compared with those in active marsh systems elsewhere. The overall situation is further complicated by the high degree of variation in the inputs and organic loading of fresh water inflow to the system. It seem likely, however, that invertebrate and fish communities in these lochs benefit significantly from the input of organic matter of terrestrial origin and that these intertidal plant communities themselves benefit from material of marine origin. The studies are continuing.

Figure 9. *View of Loch Beag from the south west showing the causeway and road bridge from which the flux studies were made. The sea is to the bottom right of the picture and the salt marsh lies to the right at the top of the picture.*

GRAZING MANAGEMENT AT BRAUNTON BURROWS

The work at this site during 2001 was severely restricted by the Foot and Mouth epidemic. Although apparently healthy the stock on the sites had to be destroyed as part of the contiguous cull thus the site was effectively ungrazed for the whole year. The summer recording was however permitted under a special licence. The results confirmed the expectation that the co-incidence of a favourable wet growing season combined with the very low level of grazing would enable the more vigorous plant species to increase considerably. The unfortunate circumstances of 2001 underlined the importance of having and maintaining an appropriate level of grazing for the maintenance of plant species diversity in key areas of conservation interest. The re-establishment of grazing in 2002 and the next few years of monitoring are awaited with great interest.

CHANGES IN THE MACHAIR AT SEILEBOST

Environmental pressures are affecting coastal habitats around the entire coast of the British Isles. In many places the main causes are increasing human pressure on delicate coastal ecosystems with the impact of ever-increasing industrial or recreational developments or the effects of pollution and eutrophication. The Western Isles may seem far removed from all this but at Seilebost, on the Isle of Harris, there is a long spit of machair which is continually subject to the process of change under the influence of the wind and the waves. Over recent years there appear to have been considerable losses from erosion and with the help of staff and pupils of Seilebost School, situated on this spit, L A B Coastal has been monitoring changes here for the past three years (see previous L A B Coastal - Annual Reports). The fall in the rate of erosion along the machair edge noted in 2000 has largely continued although there was a temporary increase during the summer of 2002. A notable feature of recent changes in the Seilebost machair has been a notable decrease in the rate of erosion during the summer months and a rather smaller increase in the rate of erosion during the winter months. This may well be related to the precise timing of significant storms during this period and this matter is being investigated. Recent reports of research at Stornoway have indicated that the land there is sinking very significantly in relation to the level of the sea and this could also be significant for changes at Seilebost less than forty miles to the south-west. However, the Stornoway data needs to be confirmed by the collection of further survey data.

It must also be noted that in 2000 there had been a significant area where the sand banks at the tip of the peninsular were showing signs of being recolonised by vegetation and this area was still visible in 2001 (Fig. 10). The area actively being colonised by vegetation is, however, very small in comparison with the total area lost to erosion.

Figure 10. *View of the machair at Seilebost, Harris from the south west. The proximal half of the west (seaward) face shows a degree of stability with the face being colonised by vegetation while the distal sectors shows signs of active erosion. The area of colonisation and growth can be seen on the far side of the distal end of the spit.*

RESEARCH ARTICLE

"NITROMOD" – a model of nitrogen fluxes in salt marshes

By *John Hazelden*, L A B Coastal

INTRODUCTION

As part of LAB Coastal's contribution to the EC-funded project, EUROSAM (Contract No. ENV4-CT97-0436) a model was built in order to examine the nitrogen fluxes in salt marshes (Boorman *et al.* 2000). NITROMOD was constructed by examining published nitrogen models and using parts of them, adapted where necessary, to build a model that was applicable to salt marshes. Brief mention of the model was made in the LAB Coastal Annual Report for 2000 (pages 8 to 9) and it is presented here in more detail.

NITROMOD uses the software ModelMaker 3 (Cherwell Scientific Publishing Ltd. 1997), and its structure is shown in Figure 11. For many salt marsh sites there are only limited data and it was decided that the model had to be able to run with the available data. It deals, therefore, only with those parts of the nitrogen cycle for which we have adequate information. Many models dealing with the nitrogen cycle have been designed for agricultural crops and farmland, and so are concerned with very different conditions from those which are found on salt marshes. It was necessary, therefore, to consider the ways the processes within the salt marsh differ from those in terrestrial habitats. In addition many published nitrogen models have been designed to examine aspects of nitrogen cycling such as the efficient use of fertilizers and the reduction of nitrate leaching loss in order to protect water supplies, and so have limited relevance to the salt marsh. There are models which examine nitrogen in wetlands (e.g. Jørgensen, 1994) but these are commonly concerned with the removal of nitrogen from water flowing through the wetland.

Since 1990 the EUROSAM teams have collected data on plant productivity, standing crop biomass, and nutrient and sediment fluxes, usually on a monthly timestep, from marshes in the United Kingdom, France, The Netherlands and Portugal. However, these data are limited and only short, and often incomplete, runs of data are available. NITROMOD has been constructed using the data collected from the lower marsh at Tollesbury in the UK (Lefeuvre *et al*. 1993, 1994, Boorman *et al*. 1994a, 1994b, Boorman 1996, Hazelden & Loveland 1996). Some additional data on water, soil, sediment and plant nitrogen were collected from the lower marsh at Tollesbury during the EUROSAM project.

It was regarded as important to try to fit the model around our data rather than to model theoretically processes about which there is little information. The site at Tollesbury, Essex, UK, is similar to many European salt marshes but very different to those in the Baie de Mont St. Michel, Brittany, France (Vivier 1997). Some aspects of nitrogen cycling have not been modelled as they are allowed for in the input data (e.g. plant uptake). The model is still being developed and is being linked to the ANCOSM model (Boorman *et al.* 2000).

THE MODEL

The structure of the model (NITROMOD) is shown in Fig. 11. In previous studies we had determined that the majority of the roots of the marsh plants at Tollesbury were in the top 200 mm of the soil (Boorman *et al*. 1994a, Hazelden and Loveland 1996). The marsh surface at Tollesbury is accreting at an average rate of about 0.3 mm per month (4 mm per year - Boorman et. al., 1998). This is very slow in relation to the rooting depth and, as an approximation therefore, NITROMOD treats the soil as a single layer 200 mm thick. The ways in which the model deals with three of the main processes – ammonification, nitrification and denitrification are described below. The units used are g m^{-2} unless otherwise stated. The model used a monthly time-step and rates of change are expressed in g m^{-2} $month^{-1}$.

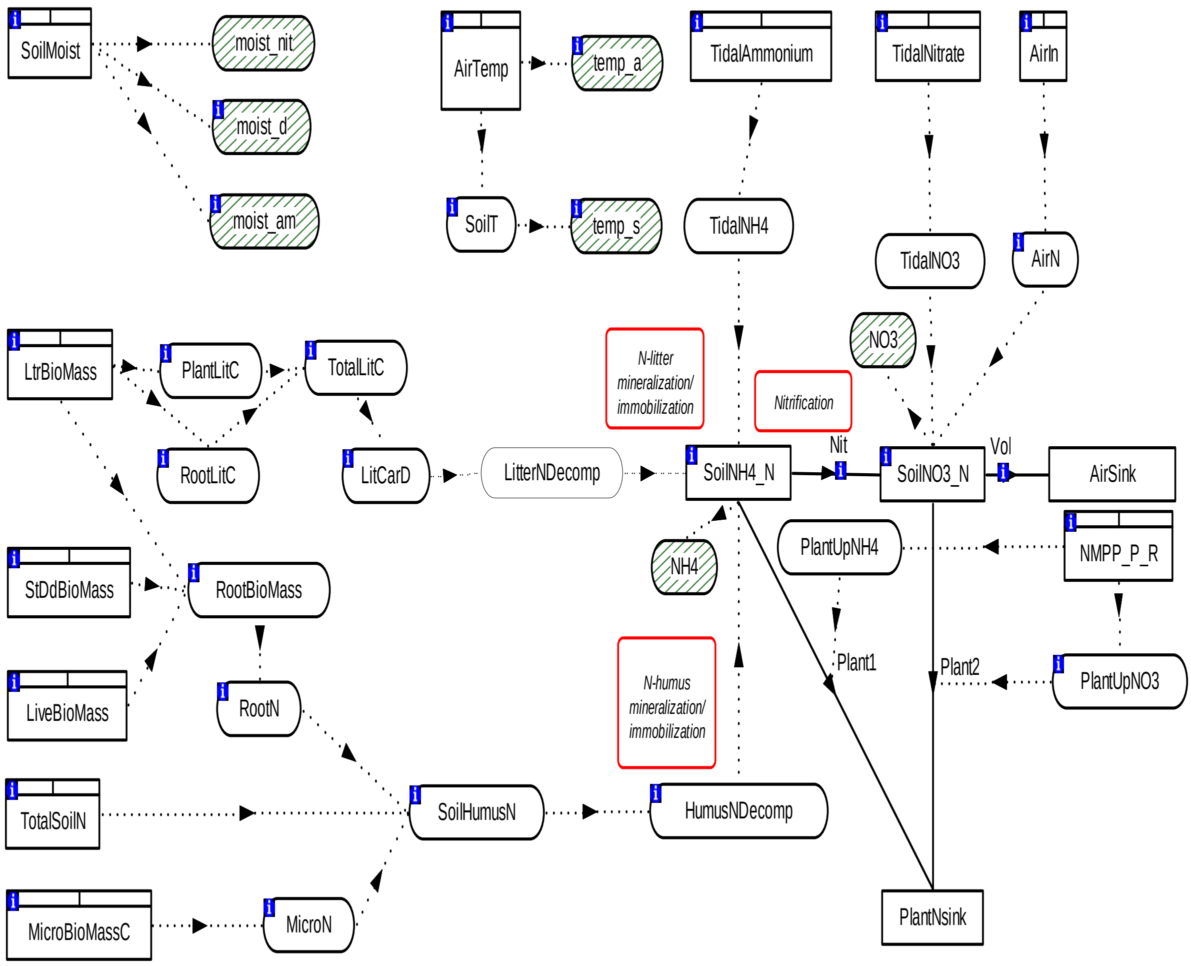


Figure 11. *The structure of the NITROMOD model*

AMMONIFICATION

This is dealt with in two parts. The dominant process is the breakdown of plant and root litter. This is dealt with as a first-order rate reaction controlled by the rate of litter decomposition and the amount of litter carbon present (TotalLitC) (e.g. Johnsson *et al*. 1987, Bergström & Jarvis 1991, Hutson & Wagenet 1991). The root litter is assumed to be equal to the above ground litter and it is assumed that all the root litter and 50% of the above ground litter is incorporated into the soil. The organic carbon content of this litter is taken as 45%. The decomposition rate is influenced by both soil moisture content and soil temperature, and the model allows for these variables. The effect of soil moisture content (θ) is controlled as in Johnsson *et al*. (1987) by a factor (moist_am) which varies from 0 to 1, declining from 1 if the soil is either too wet or too dry. When the soil is wetter than optimum, i.e. between θ_s and (θ_s-θ_{hi}) the equation is

$$moist\_am = e_s+(1-e_s)(\theta_s-\theta)/\theta_{hi}$$

where θ_s is the water content (% volume) at saturation (-0.01 kPa), θ_{hi} is the range over which the decomposition rate decreases in wet soils (15%) and e_s is the value of moist_am at saturation (0.6). When the soil is within the optimum range, i.e. between (θ_s-θ_{hi}) and (θ_w+θ_o), then

$$moist\_am = 1$$

where θ_w is the water content (% volume) at wilting point (-1500 kPa) and θ_o is the range over which the decomposition rate reduces from 1 to 0 in dry soils (20%). When the soil water content is lower than the optimum range then

$$moist\_am = (\theta-\theta_w)/\theta_o$$

The salt marsh soils at Tollesbury do not generally dry out sufficiently for this last condition to operate.

Temperature is controlled by a factor which similarly varies between 0 and 1 and is defined as

$$temp\_s = 2^{((SoilT-20)/10)}$$

where SoilT is the mean monthly soil temperature (degrees C). This assumes a factor change of 2 for a temperature change of 10° C (e.g. Campbell *et al.* 1984) and an optimum temperature of 20° C. Soil temperature was not measured but is derived from air temperature (measured at Tollesbury) according to the equation

$$SoilT = (AirT-0.29)/1.13$$

where AirT is the mean monthly air temperature (degrees C) (Henriksen & Jensen 1979); this relationship was derived for soils in similar temperatures to those at Tollesbury.

The production of carbon from the decomposition of soil litter (LitCarD) is then given by

$$LitCarD = k_l \times moist\_am \times temp\_s \times TotalLitC$$

where k_l is the rate constant for this reaction, here set at 0.4 month^{-1} from measurements made at Tollesbury (Boorman 1996). The mineralization or immobilisation of NH_4-N (LitterNDecomp) is then determined by the C:N ratios of the litter (p_c/p_n) and of the microbial biomass (r_{mi}).

$$LitterNDecomp = ((p_n/p_c)-(f_e/r_{mi})) \times LitCarD$$

where f_e relates to the efficiency of the microbial biomass in using the decomposing plant litter (set at

0.6 from data collected at Tollesbury). It is assumed here that the percentage of N and C in the live plant and litter material are the same.

The second process modelled is the breakdown of soil humus to give ammonium-nitrogen. This is done in a similar way with the reaction controlled by the rate of breakdown (k_h – estimated at 0.02 month^{-1}) of soil humus and the amount of humus nitrogen present (SoilHumusN), as in Johnsson *et al*. (1987). The amount of humus nitrogen present is determined from the total soil nitrogen minus that in the roots and in the microbial biomass. The total soil nitrogen and the biomass N are regarded as constant as we do not have sufficient data to treat these differently. Thus, the amount of ammonium-nitrogen generated, HumusNDecomp, is given by

$$\text{HumusNDecomp} = k_h \times \text{moist\_am} \times \text{temp\_s} \times \text{SoilHumusN}$$

NITRIFICATION

Some nitrogen models (e.g. Johnsson *et al*. 1987, Bergström & Jarvis 1991, Hutson & Wagenet 1991) derive soil NO_3-N content by assuming a constant ratio, subject to minimum concentrations, of NH_4-N to NO_3-N. This treatment is inappropriate for anaerobic salt marsh soils and so nitrification is dealt with differently here, following the method of Bradbury *et al.* (1993). The process is again treated as a first-order rate process, missing out the nitrite intermediary, and the rate is modified according to soil moisture and air temperature. Soil moisture is treated in a somewhat different way using a factor moist_nit which varies between 0 and 1. It is assumed that nitrification will take place at its optimum, although slow, rate as the soil dries from field capacity (θ_{fc}, -5kPa) to –100kPa (θ_{100}). Thus if $\theta_{fc} > \theta > \theta_{100}$

$$\text{moist\_nit} = 1$$

If $\theta < \theta_{100}$, then

$$\text{moist\_nit} = 1-(1-s)((\theta 1-\theta)/(\theta 1-\theta_w)$$

s is set at 0.6 and moist_nit approaches 0.6 as θ approaches θ_w. However, in salt marsh soils, θ is often greater than θ_{fc}, and in this range conditions are similarly less than optimum, although this possibility was not addressed by Bradbury *et al*. (1993) who were working in a very different environment. Thus, if $\theta_s > \theta > \theta_{fc}$

$$\text{moist\_nit} = 1-((\theta-\theta_{fc})/(\theta_s-\theta_{fc}))$$

The temperature modifier used is that of Jenkinson *et al*. (1987). This modifier, temp_a, is defined as

$$\text{temp\_a} = 47.9/(1+e^{(106/(\text{AirT}+18.3)})$$

where AirT is the air temperature in degrees C. The rate of nitrate formation from NH_4-N ($N_{NH4\text{-}NO3}$) is given by

$$N_{NH4\rightarrow NO3} = \text{SoilNH4\_N}(1-e^{(-kn \times \text{moist\_nit} \times \text{temp\_a})})$$

where SoilNH4_N is the amount of NH_4-N in the soil at the beginning of the month and k_n is a rate constant set at 0.54 month^{-1}. The rate constant used by Bradbury *et al*. (1993) was 0.6 week^{-1}, but Aziz and Nedwell (1979), working on the Essex marshes, concluded that there was very little or no nitrification (and so no denitrification), and so the rate (k_n) has been set much lower than that used by Bradbury *et al*.

DENITRIFICATION

This is again a first-order rate reaction controlled by the potential denitrification rate (k_d) and the amount of NO_3-N in the soil (e.g. Johnsson *et al*. 1987, Bergström & Jarvis 1991, Hutson & Wagenet 1991). k_d is set at 0.34 month^{-1} from the data of Aziz and Nedwell (1979); data from Portugal (Bettancourt, pers. comm.) suggests much higher rates of up to 8.0 month^{-1} in the Mira estuary. The rate constant is modified to allow for temperature and soil water content, the latter as an expression of soil aeration. The temperature modifier, temp_s, is the same as used previously, but the moisture modified is different as denitrification is an anaerobic process. The modifier, moist_d, varies between 0 and 1. If $\theta < \theta_d$, then

$$\text{moist\_d} = 0$$

where θ_d is the water content below which there is no denitrification (set at 20%). If $\theta > \theta_d$, then

$$\text{moist\_d} = ((\theta-\theta_d)/(\theta_s-\theta_d))^d$$

where d is an empirical constant, here set at 1. The denitrification rate ($N_{NO3\rightarrow N}$) is then

$$N_{NO3\rightarrow N} = k_d \times \text{moist\_d} \times \text{temp\_s} \times (\text{SoilNO3\_N}/(\text{SoilNO3\_N}+c_s))$$

where SoilNO3_N is the NO_3-N content of the soil and c_s is the half-saturation constant, set here at 1.

INPUT DATA

The model is controlled by the data tables which are derived from the work carried out in the EUROSAM project and its predecessors. We do not have enough detailed data to allow proper monthly time-steps in all cases and so the monthly input or output has been estimated or treated as constant (e.g. biomass, tidal fluxes, aerial input).

The model is driven by the plant biomass figures, which are given in the look-up tables. There are separate figures for living plant material, standing dead material and for litter. Root biomass is assumed to be the same as that above ground, and in the same three categories. Microbial biomass is regarded as constant at Tollesbury, but this was not the case at Stiffkey (Hazelden & Loveland 1996).

The biochemical processes are affected by soil moisture and soil temperature; moisture figures are provided from a look-up table in the model and temperature is derived from air temperatures (Henriksen & Jensen 1979) measured over the sampling period.

Tidal fluxes of ammonium- and nitrate-nitrogen (in solution and in suspended sediment) are estimates from data collected at Tollesbury between 1990 and 1994. There are not enough data to provide reliable estimates of monthly figures, which are probably dominated by storm events of which we have no record, but an indication of the suggested monthly pattern is shown in the estimated values given in the look-up tables. It could be argued that constant values should be used. Indeed, the aerial input of nitrogen (Goulding 1990, Koerselman &Verhoeven 1992) to the system is regarded as constant as rainfall is fairly uniform and we have no other data.

Estimate of the uptake of nitrogen by plants has been made from the Net Annual Primary Production (NAPP), which was measured at Tollesbury. The plants use both NH_4-N and NO_3-N in proportion to their relative concentration. However, zones around the roots of the salt marsh plants are often relatively aerobic, partly due to the pores formed by the roots themselves, so nitrogen uptake may be biased towards NO_3-N.

There are some elements of the nitrogen cycle missing in the processes described above, but these are currently effectively included in the input data. For instance, the breakdown of litter gives CO_2 and humus as well as mineral N. CO_2 is lost to the atmosphere and the humus adds to the humus pool in the soil. However, humus N is calculated monthly from the soil total N, microbial N and root N, so it is not modelled in NITROMOD.

OUTPUT OF MODEL

Figures 12 and 13 compare the results from the model with measured values from the Tollesbury salt marsh (lower marsh) for soil NH_4-N and NO_3-N respectively. These are the data around which the model was constructed. To test the model against other data not used in its construction, NITROMOD has been run with the data from the pioneer zone at Tollesbury (Figures 14 and 15) and the middle marsh at Stiffkey (Figures16 and 17). These outputs are discussed below. The model has not been run with data from the French, Dutch or Portuguese marshes as there is not sufficient soil nitrogen data from these sites against which to calibrate the model.

The fluctuations in, and the incomplete nature of, the measured data meant that it was not practical to carry out statistical tests of goodness of fit or to use the optimization routines available within ModelMaker 3. Optimization of some parameters which had been estimated rather than measured was carried out by running the model many times with the different values until the best fit was found.

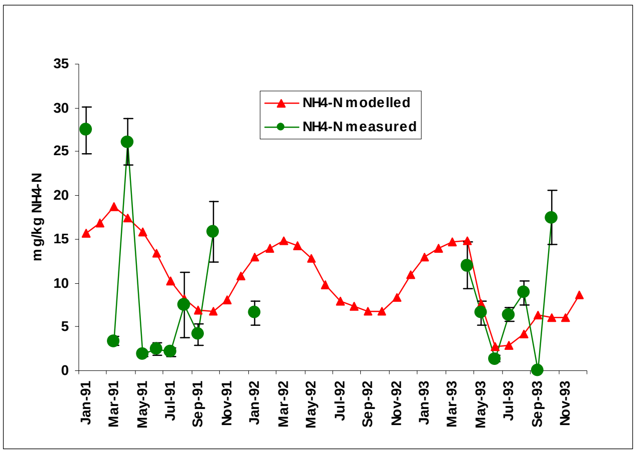


Figure 12. *Comparison of modelled and real soil NH_4-N data (±SE) for Tollesbury Lower Marsh. The model smooths out the large variations in the real data, which were used to build the model.*

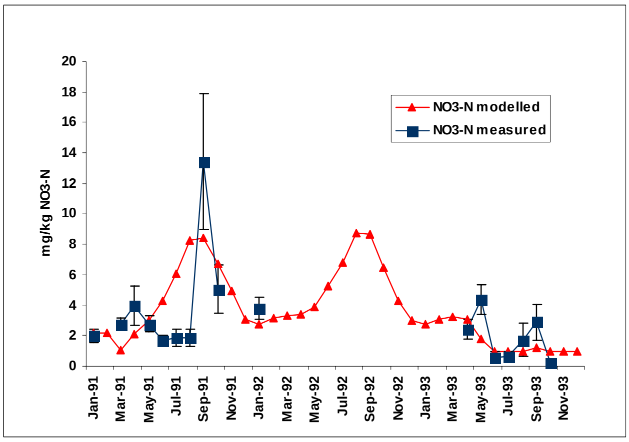


Figure 13. *Comparison of modelled and real soil NO_3-N data (±SE) for Tollesbury Lower Marsh. The model smooths out the large variations in the real data. Results from the model are a better fit to the NO_3-N data than to the NH_4-N data.*

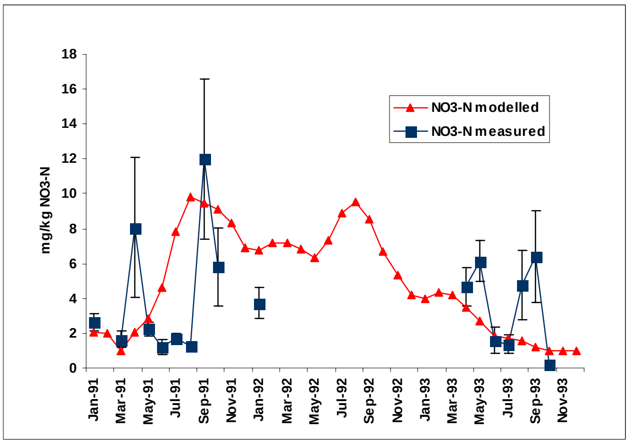


Figure 14. *Comparison of modelled and real soil NH_4-N data (±SE) for Tollesbury Pioneer Zone. The real data is more variable than the model predicts.*

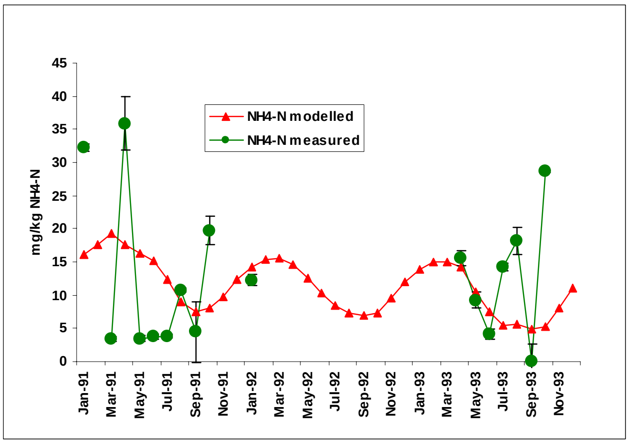


Figure 15. *Comparison of modelled and real soil NO_3-N data (±SE) for Tollesbury Pioneer Zone. The real data is again more variable than the model predicts.*

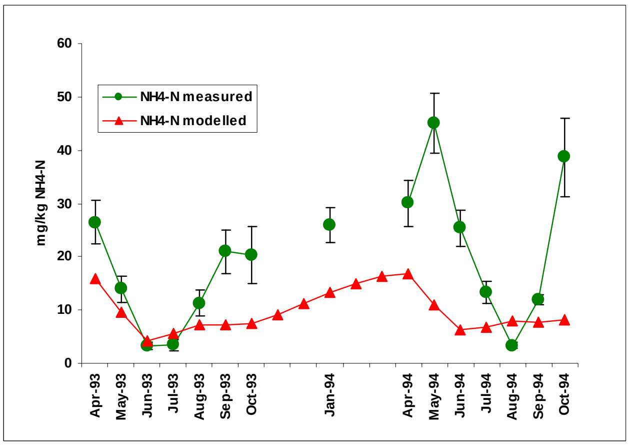


Figure 16. *Comparison of modelled and real soil NH_4-N data (±SE) for Stiffkey Middle Marsh. The fit of the modelled data is not as good here as at Tollesbury. The model underestimates the levels of NH_4-N in the soil.*

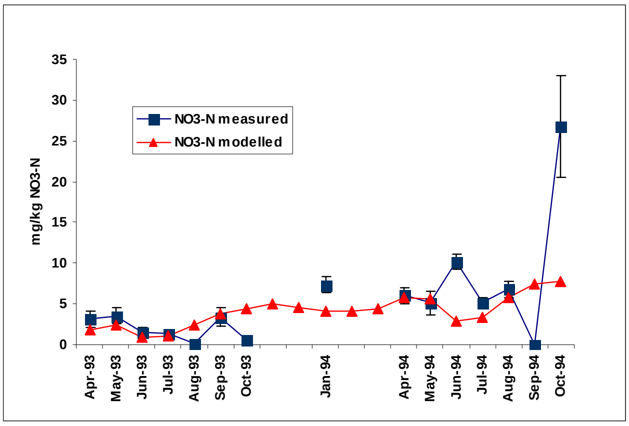


Figure 17. *Comparison of modelled and real soil NO_3-N data (±SE) for Stiffkey Middle Marsh. The fit here is better that for NH4-N.*

DISCUSSION

The actual values of soil NH_4-N are much more variable than the values modelled by NITROMOD in Figure 12, although the overall trends appear much the same. The measured NO_3-N values are slightly less variable and somewhat closer to the modelled figures (Figure 13).

There are many possible explanations for the discrepancies seen in Figures 12 and 13. The model seems capable of predicting soil nitrogen concentrations of the correct order, but the concentrations of the relative nitrogen species change very rapidly in response to changes in soil temperature, moisture and aeration, and to plant uptake. The model uses a monthly timestep and so cannot predict these fluctuations. A timestep of a day or even one of a few hours would be much better, but we do not have enough detailed data for most of the attributes to be able to run the model in this way.

In addition to the length of timestep, there are several possible explanations for the discrepancies seen in Figures 12 and 13. Our earlier studies suggested a strong direct link between the amount of litter and soil NH_4-N (Lefeuvre *et al*. 1993, Boorman *et al*. 1994a), but this was not supported by subsequent studies, possibly because of changing patterns of vegetation (Boorman 1996, Hazelden & Loveland 1996). The distribution and relative amounts of the various salt marsh species influence the levels of soil NH_4-N, probably by affecting the way plant litter is trapped on the marsh surface. In addition, different species have different C:N ratios and their litter will have different rates of breakdown which it has not been possible to build into the model at this stage. Soil moisture data from samples collected for other analyses have been used in the model and these may be unrepresentative in that the marsh is inundated regularly by spring tides and so the pattern of soil wetness is much more complex than allowed for here.

For the pioneer marsh at Tollesbury, the measured data are again much more variable than the model predicts. However, the model predicts values of the correct order, and so the discrepancies are probably due to the same reasons as those given above. At Stiffkey the model predicts much lower soil NH_4-N figures than were actually recorded, although the pattern is similar. There are probably many reasons for this, but there is less available data for Stiffkey than for Tollesbury and it may be that the data driving the model need correction. At Stiffkey, as at Tollesbury, the model is better at predicting soil NO_3-N than soil NH_4-N.

CONCLUSIONS

NITROMOD works reasonably well, particularly for soil NO_3-N, but could be substantially improved. Data collected more frequently, and for longer complete runs, which would allow the model to function with a much shorter timestep, may help reduce some of the differences between the apparently erratic real data and that which has been modelled. Also, the model needs to be able to run spatially to enable it to take account of different vegetation patterns across the marsh.

Work is continuing on the various aspects of NITROMOD indicated above as well as on the integration of NITROMOD with ANCOSM, the model of the cycling of organic matter also developed as part of the contribution of L A B Coastal to the EUROSAM project.

REFERENCES

Aziz, S.A. Abd. & Nedwell, D.B. 1979 Microbial nitrogen transformations in the salt marsh environment. In: R.L. Jeffries & A.J. Davy (eds) *Ecological processes in coastal environments*. Blackwell, Oxford, 385-398.

Bergström, L. & Jarvis, N.J. 1991 Prediction of nitrate leaching losses from arable land under different fertilisation intensities using the SOIL-SOILN models. *Soil Use and Management*, 7, 79-85.

Boorman, L.A. 1996 *The effects of environmental change on European salt marshes: structure, functioning and exchange potentialities with marine coastal waters*. Final Report of EC contract no. EV5V CT92 0098, Volume 5. Laboratoire d'évolution des systèmes naturels et modifiés, Université de Rennes, France.

Boorman, L.A., Garbutt, R.A. & Barratt, D. **1998**. The role of vegetation in determining patterns of the accretion of salt marsh sediment*. Sedimentary Processes in the Intertidal Zone*. Eds. K.S.Black, D.M.Paterson & A.Cramp. Geological Society Special Publication, **139**, 389-399.

Boorman, L.A., Hazelden, J., Loveland, P.J., Wells, J.G. & Levasseur, J.E. 1994a Comparative relationships between primary productivity and organic and nutrient fluxes in four European salt marshes. In: W. J. Mitsch (ed.) *Global Wetlands: Old World and New*. Elsevier, Amsterdam, 181-199.

Boorman, L.A., Hazelden, J., Andrews, R.P. & Wells, J.G. 1994b Organic and nutrient fluxes in four north-west European salt marshes. In: K.R. Dyer and R.J. Orth (eds.) *Changes in Fluxes in Estuaries: Implications from Science to Management*. ECSA 22/ ERF Symposium, Olsen and Olsen, Fredensborg, Denmark, 243-248.

Boorman, L.A., Hazelden, J. & Boorman, M.S. 2000 EUROSAM –TASK 6. Final Report. *Analysis of the nutrient control of the organic carbon cycle in a salt marsh (ANCOSM) and the modelling of the nitrogen cycle (NITROMOD).* L A B Coastal, Holywell.

Bradbury, N.J., Whitmore, A.P., Hart, P.B.S & Jenkinson, D.S. 1993 Modelling the fate of nitrogen in crop and soil in the years following application of 15N-labelled fertilizer to winter wheat. *Journal of Agricultural Science*, 121, 363-379.

Campbell, C.A., Jame, Y.W. & Winkleman, G.E. 1984 Mineralization rate constants and their use for estimating nitrogen mineralization in some Canadian prairie soils. *Canadian Journal of Soil Science*, 64, 333-343.

Cherwell Scientific Publishing Limited. 1997 *ModelMaker 3.* Oxford, UK.

Goulding, K.W.T. 1990 Nitrogen deposition to land from the atmosphere. *Soil Use and Management*, 6, 61-66.

Hazelden, J. & Loveland, P.J. 1996. *The effects of environmental change on European salt marshes: structure, functioning and exchange potentialities with marine coastal waters.* Final Report of EC contract no. EV5V CT92 0098, Volume 4. Laboratoire d'évolution des systèmes naturels et modifiés, Université de Rennes, France.

Henriksen, K. & Jensen, A. 1979 In: R.L. Jeffries & A.J. Davy (eds) *Ecological processes in coastal environments*. Blackwell, Oxford, 373-384.

Hutson, J.L. & Wagenet, R.J. 1991 Simulating nitrogen dynamics in soils using a deterministic model. *Soil Use and Management*, 7, 75-78.

Jenkinson, D.S., Hart, P.B.S., Rayner, J.H. & Parry, L.C. 1987 Modelling the turnover of organic matter in long-term experiments at Rothamsted. In: J.H. Cooley (ed.) *Soil organic matter dynamics and soil productivity.* INTECOL Bulletin 15, 1-8.

Johnsson, H., Bergstrom, L., Jansson, P-E. & Paustian, K. 1987 Simulated nitrogen dynamics and losses in a layered agricultural soil. *Agriculture, Ecosystems and Environment*, 18, 333-356.

Jørgensen, S.E. 1994. A general model of nitrogen removal by wetlands. In: W. J. Mitsch (ed.) *Global Wetlands: Old World and New*. Elsevier, Amsterdam, 575-583.

Koerselman, W. & Verhoeven, J.T.A. 1992 Nutrient dynamics in mires of various trophic status: nutrient inputs and outputs and the internal nutrient cycle. In: J.T.A. Verhoeven (ed.) *Fens and bogs in The Netherlands: vegetation, history, nutrient dynamics and conservation.* Kluwer Academic Publishers, Dordrecht, The Netherlands, 397-432.

Lefeuvre, J-C., Dankers, N., Boorman, L., Loveland, P.J. & Bettencourt, A. 1993 *Comparative study on salt marsh processes*. Final report of EEC research contract no. EV4V-0172-F(EDB). Université de Rennes, France.

Lefeuvre, J-C., Bertru, G., Burel, F., Brient, L., Creach, V., Guerné, Y., Levasseur, J., Mariotti, A., Radureau, A., Retière, C., Savouré, B. & Troccaz, O. 1994 Comparative studies of salt marsh processes: Mont St Michel Bay, a multi-disciplinary study. In: W. J. Mitsch (ed.), *Global Wetlands: Old World and New*. Elsevier, Amsterdam, 215-234.

Vivier, J-P. 1997 *Influence du Paturage sur la Disponibilité de l'Azote pour l'Exportation dans un Marais Salé (Baie du Mont-Saint Michel)*, Thesis, Université de Rennes, France.

ACKNOWLEDGEMENTS

The authors wish to express their thanks to the individuals and organisations who have made these studies possible, especially to colleagues in the Institute of Terrestrial Ecology (now Centre for Ecology and Hydrology), in Scottish Natural Heritage and to the various landowners for permitting site access, and also many colleagues across Europe for their help and encouragement. The authors gratefully acknowledge the financial support of DG XII of the Commission of the European Community received under Grants EV4V-0172F, EV5V-CT92-0098 and ENV4-CT97-0436.

Financial Statement

Although the annual turnover was slightly less than that in the previous yea; investment in equipment and facilities continued. Over 90% of income was used for basic or near-basic research.

Facilities and services

LAB Coastal uses the full range of modern survey equipment and has the experience of an extensive network of specialists at its disposal. It has state of the art laboratory facilities available to complement the field monitoring equipment. Greenhouse facilities including tidal mesocosms with sophisticated control and monitoring systems are provided for experimental work.

LAB Coastal offers customised surveys to gather information on, for example, species, amount, distribution and habitats of the most important elements of the natural flora and fauna of an area.

Research is carried out to fill the numerous gaps which still remain in the understanding of ecosystem functions and interactions. The company can offer a range of tailor-made research programmes for specific clients.
Modern field techniques coupled with sophisticated data handling enable scientifically rigorous data to be obtained for providing baseline information for future management plans or for making an impact assessment. Ongoing programmes of monitoring can be maintained efficiently to ensure the effective implementation of management strategies or to confirm the validity of impact assessments.

LAB Coastal can provide management advice and programmes for natural habitats. The company also participates actively in habitat creation schemes and this experience is at the disposal of clients. In addition advice is available on low cost erosion control for coastal habitats which provides an acceptable substitute for man-made sea defence works.

Links with other organisations

LAB Coastal was a full partner in the EU-funded EUROSAM project, part of the IVth Framework, on:

1. The development of a range of models of ecological and hydrodynamic processes to predict the likely responses of various salt marsh ecosystems to environmental changes. These can include the potential impacts of predicted rise of sea level or of human activities on the functioning of salt marshes and on the fluxes of various nutrients between the salt marshes and the marine coastal waters;

2. The calibration of the process models to specific conditions encountered in various European salt marshes;

3. The linking of the process models and the hydrodynamic models through the development of a decision support system.

The other scientific partners in EUROSAM were:

University of Rennes 1, France
Centre for Ecology and Hydrology, UK
Alterra, Den Burg, The Netherlands
IMAR Marine Institute, University of Lisbon, Portugal
IMAR, University of Evora, Portugal
Higher Technical Institute, Lisbon, Portugal
Institute of Oceanography, Lisbon, Portugal
IFREMER, Brest, France.

LAB Coastal was a subcontractor in the EU funded programme Influence of rising Sea Level on Ecosystem Dynamics of salt marshes (ISLED).

The other scientific partners in ISLED were:

Centre for Estuarine and Coastal Ecology, Yerseke, The Netherlands
Laboratory of Plant Ecology, University of Ghent, Belgium
Southampton Oceanography Centre, Southampton, UK
Institute of Biology, University of Odense, Denmark
Dept. of Evolution of Natural and Modified Systems, University of Rennes 1, Rennes, France
Institute of Terrestrial Ecology (now Centre for Ecology and Hydrology), Monks Wood, Abbots Ripton, UK
Department of Plant Biology, Faculty of Science, Lisbon, Portugal

Links are also being maintained with the Australian Institute of Marine Research, Cape Ferguson, Queensland, and the Universities of Cambridge and Essex. LAB Coastal is looking forward to further co-operation with these and other research departments in the future.

Contact Points

WEB SITE

Full information about L A B Coastal including previous Annual Reports can be found on its Web Site at http://www.labcoastal.co.uk

EMAIL ADDRESSES

Individuals at L A B Coastal can be contacted by Email as follows:

Laurie Boorman (Scientific Director)	laurieb@labcoastal.co.uk
John Hazelden (Soils Consultant)	johnh@labcoastal.co.uk
Mary Boorman	maryb@labcoastal.co.uk
Administration	admin@labcoastal.co.uk

TELEPHONE

Contact can be made with L A B Coastal by telephone or facsimile (automatic) at 00 44 (0)1480 468068.

POSTAL

The correct postal address for L A B Coastal is given below:-

L A B Coastal,
The Maylands,
Holywell, St. Ives,
Cambridgeshire,
PE27 4TQ U.K.

Publications

IN PRESS

Boorman, L.A. 2001. The Role of Nutrients in Salt Marsh Processes in an Essex Estuary. ECSA Essex Meeting. (in press).

PUBLISHED

Boorman, L.A. 2001. *L A B Coastal Annual Report 2000.* L A B Coastal: Holywell, Cambridgeshire. 38 pps.

Boorman, L.A. 2001. *ISLED Final Summary Report. March, 2001.* L A B Coastal: Holywell, Cambridgeshire. 8 pps.

Boorman, L.A. 2001. *Braunton Monitoring - Assessor's Review of 2000 Main Report.* L A B Coastal: Holywell, Cambridgeshire. 9 pps.

Boorman, L.A., Hazelden, J. & Boorman, M. 2000 The effect of rates of sedimentation and tidal submersion regimes on the growth of salt marsh plants. *Continental Shelf Research*: 21, 2155-2165.

Hazelden, J. & Boorman, L.A. 2001. Soils and 'managed retreat' in South East England *Soil Use and Management* : 17, 150-154.

Boorman, L.A. & Boorman, M.S. 2000. The Spatial and Temporal Effects of Grazing on the Species Diversity of Sand Dunes. In: *Coastal Dune Management. Shared Experience on European Conservation Practice*. Ed. J.A. Houston, S.E. Edmondson and P.J. Rooney. Liverpool University Press. 161-167.